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13. ABSTRACT (Maximum 200 words) The research program funded the purchase of servo-hydraulic mechanical test equipment ideal for conducting tests on ceramic composites. Further, in order to carry out research on this machine, special grips, suitable for brittle materials, and a special furnace were purchased under this grant.				
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FINAL REPORT

**"Mechanical Behavior Investigation of Advanced Ceramic
Matrix Composite Materials"**

by

**J. Sankar
A. D. Kelkar**

**Department of Mechanical Engineering
North Carolina A & T State University
Greensboro, NC 27411**

Submitted to

**AFOSR/PKA
110, Duncan Avenue, Suite B115
Bolling AFB, DC 20332-0001**

**AFOSR Grant #F49620-93-1-0573
Program Manager: Charles H. Ward, Captain, USAF**

BACKGROUND

The Center for Composite Materials (CCMR), an authorized official center of the University of North Carolina System at the North Carolina A & T State University has been active for the past ten (10) years conducting research on advanced high temperature materials. Although the center has several instruments to characterize the various aspects of advanced material systems, the procured research/instructional instrumentation will upgrade existing research facilities for addressing basic research needs of the present and future. Further, the acquired research instrumentation will improve the capacity of the University to perform research of direct interest to DoD missions.

The present research program funded a servo-hydraulic mechanical test equipment ideal for conducting tests for ceramic composites. We are already in touch with various agencies for advanced ceramic research work using this equipment. Further in order to carry out the research on this machine special grips (suited for brittle materials) and a special furnace have been purchased using this grant. Further we have acquired special strain extensometer that can work at 1200°C, suitable for high temperature ceramics projects.

Although we do have test machines at N. C. A & T State University, they are funded and solely supported by other research contracts for their on-going research work. We feel by having a machine of this kind from DoD research, long range research commitment can be made in advanced materials research between N. C. A & T State University and DoD. In addition, advanced instruments such as the one purchased can be used very effectively as an instructional tool. At present, our undergraduate students in their senior year visit our mechanical testing laboratory as part of their materials laboratory course. The procured equipment along with the proposed research work will not only educate the students on the state of art technology and basic research but also simulate interest to join graduate studies or the Department of Defense as a career move.

EQUIPMENT DESCRIPTION

The equipment purchased is an Instron 8511 Dynamic Testing System. This system was manufactured at

Instron Corporation
100 Royall Street
Canton, Mass. 02021

while all purchase orders were negotiated through

Instron Corporation
3815 Presidential Parkway
Suite 100
Atlanta, GA 30340

Detailed description of the test equipment along with various important items purchased are given below.

Instron 8511 Dynamic Testing System

1. 41Kn (9.2 kip) Stand Alone Fatigue System.

The system controlled by the 8500 digital control console including load and position controllers with 32 bit function generators for a wide range of waveforms. The system allows the addition of 2 strain controllers and 8 channels of data acquisition using the high speed data acquisition card.

2. 8500 Control Provides Dual User-Interface

Manual User Interface via operator front panel, which can be located close to the specimen test area. Full access to 8500's control features is provided using either menu driven key strokes, or a rotary scroll key.

Computer Interface via Industry Standard GPIB (IEEE), providing full access to the front panel commands. This allows use of Instron's full application software suite.

3. Actuator +/- 9.2 KIP Dynamic Force capacity, 4 inch stroke, incorporating a transducer for precise measurement and control of actuator position. The piston rod includes an axial 1"-14 thread for attachment of grips and fixtures.

The maximum frequency of operation is 5Hz. Dynamic force of the Actuator is 9.2 KIP. The 2.5 gpm servovalve is fitted to the actuator manifold.

4. 2 gpm 1500 PSI 120V 60 Hz AC single phase air cooled power pack incorporated in the base of the machine designed for maximum safety includes protection devices that operate in the event of low oil level, motor overloads, or high oil temperatures.
5. Load Cell +/- 9.2 KIP, incorporating 1"-14 TPI thread for attachment of grips and fixtures. Load cell is calibrated for 4 KIP.
6. ORNL Super Grip, Universal Coupling (1 set). Capacity: 7870 lbs. Tension only.
7. ORNL Water-cooled, buttonhead-specimen holders for use with Instron's two-zone slotted, short furnace. Coupling is Type I.

The Super Grip Universal Coupling is an entirely self-contained device with eight interconnected hydraulic pistons guided by linear bearings, capable of self-aligning under tensile loads. The Coupling does not require external hydraulic power for activation. It includes coaxial female threads, on both ends; to mount to the test accept either the water-cooled, buttonhead-specimen grip ends (holders) or other optional specimen holders. The water-cooled, buttonhead-specimen grip ends included have been designed for use with Instron's two-zone slotted, short furnace. The Universal coupling is suitable for testing only in tension; for static, quasi-static, and cyclic tests.

Capacity: 35KN (7,870 lbs.), tension only
 Mounting: Type I (M30RH female thread) holders
 Included: Water-cooled, buttonhead-specimen holders
 Requires: Attachment Kits
 Optional: Other holders available upon request

8. FLAPS PLUS AND SERIES IX provides software to satisfy static and dynamic testing requirements for the Instron 8500.

FLAPS PLUS is an advanced functions software program capable of performing a broad variety of applications with intelligent control and data acquisition. Powerful features include:

- Password security
- Laboratory Manager
- Test Preview facility
- Real-Time Test displays
- 12 channel data acquisition support (with Instron 133 board)
- Spreadsheet database
- Versatile post-test processor

SERIES IX is a comprehensive software package supporting tensile, compressive,

flexural, relaxation testing including:

- 640+ calculation library
- real-time test display
- instantaneous results display
- reanalysis capability

9. 1600°C Capacitive Extensometer, +/-1.0 mm range, 25mm gage length.
10. SiC knife edges for 1600°C Capacitive Extensometer.
11. Capacitive Extensometer Integration and Configuration for 8511 System.

This axial extensometer is intended, specifically, for high temperature testing of brittle materials, primarily ceramics. Two ceramic knife edges (SiC), pivoting at their center, are used to transmit the strain deformation of the sample to a capacitive transducer mounted outside the furnace. It has a 25mm (1 in.) gage length. It is fully compatible with Instron's Short Furnace, for use up to 1600°C. Signal conditioning for the capacitive transducer is provided, which produces an output of +/- 10V.

12. ORNL Super Grip specimen holders for flat specimens. Must be used in conjunction with Super Grip universal coupling. Contain one set of faces for thickness range 6-9 mm.
13. High Precision Calibrator (good for either 0.1MM of 1.0MM travel capacitive extensometers) with universal mounting.

High Precision Calibrator includes convenient universal swing-away mounting to calibrate the extensometer while in the load frame. The calibrator is good for both the 0.1mm and 1.0mm range 1600°C Capacitive Extensometers.

14. 1600°C (2910°F) Two-Zone, Short Furnace with appropriate mounting designed for use with Capacitive Extensometer.
15. Programmable controller for the 1600°C Furnace.
16. DT 486/DX 2-66/8 MB/256 Cashe/Tower

- 3 1/2 1.44 and 5 1/4 1.2 Floppy Drives
- Fujitsu 1 Gig Fast SCSI 11 Hard Drive
- Future Domain Fast SCSI Controller
- 1 Parallel and 2 Serial Ports
- 1024 x 768.28 Non-Interlaced 14' SVGA Monitor
- w/ 1 MB SVGA Adapter
- 101 Keyboard

- DOS 6.2 - Windows 3.1 - 3 Button Mouse
- SMC 16 Bit Ethernet BNC

IMPACT ON RESEARCH PROGRAMS:

The above described equipment will be used in both on-going and various future research programs. This equipment will be used immediately in two (2) of our on-going programs.

On-going Programs:

1. **Department of Energy, Advanced Heat Engines Ceramic Materials Program**

Materials Investigated: GTE SNW-1000 (sintered), PY6 (HIPed) Silicon Nitrides, Allied Signal GS 44 sintered Si_3N_4 .

Mechanical Tests: Tensile, Fatigue, Creep, Fatigue-Creep Interaction, Residual Strength, and Thermal Soaking Effects. Tests will be conducted at different temperatures. (Room to 1300°C).

Students Involvement: Two (2) Masters and one (1) Ph.D, with up to two (2) undergraduate students.

2. **Department of Energy, Continuous Filament Ceramic Composites Program**

Material Investigated: Nicalon Fiber reinforced SiC matrix with 0.3 micron thick pyrolytic graphite coating on fibers (0/90 plain weave stack).

Mechanical Tests: Tensile and Fatigue. Test will be conducted at different stressing rates and temperatures.

Students Involvement: One (1) Ph.D.

Future Programs:

We are exploring the possibilities of writing proposals to various agencies using this equipment. We have just written one (1) proposal to NASA Lewis where, if funded, the procured equipment will be used extensively.

This proposal is being submitted to the National Aeronautics and Space Administration, Lewis Research Center, in response to Solicitation No. NRA-95-LeRC-1.

North Carolina A & T State University, along with its team member Applied Research Associates, proposes to develop a new mechanistic model to characterize the constitutive behavior of CMC's under monotonic and cyclic loadings at both room and high temperatures. The method will not rely on case-specific empirical and curve-fitting parameters. While several empirically-based or mechanistically-based models have been proposed to characterize the mechanical behavior of CMC's, they are not valid at high temperatures and under cyclic loading conditions. Also, the shear lag constants used in these models are independent of interfacial parameters.

For the purpose of examining the progressive failure mechanism and to understand and validate the developed mechanistic constitutive model, both tensile tests and fatigue tests will be performed on unidirectional-reinforced ceramics composites at room and high temperatures. Optical, scanning electron microscopy and replicate technique will be used to quantify the bonding strength from measurable parameters. Experimental measurements will be compared with analytical predictions.

Specifically, the purpose of this proposed work is to understand the mechanical behavior and failure process that takes place in CMC composites under various uniaxial loading conditions. The expected results will be the development of a new mechanistic constitutive model for these materials.